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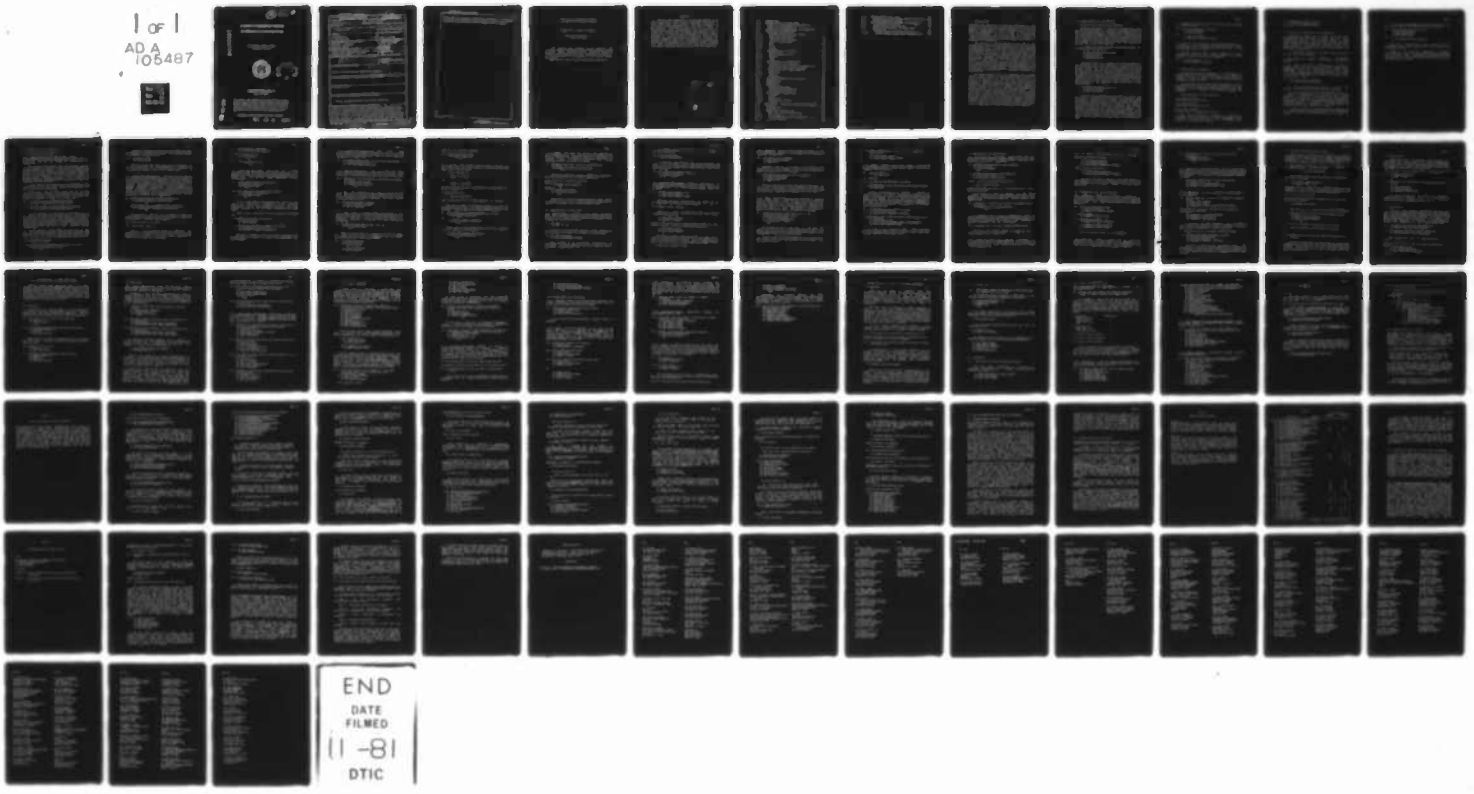


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A Guide to Propositional Analysis for Research on Technical Prose

Susan Bovair & David E. Kieras
University of Arizona

Technical Report No. 8
July 10, 1981

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Recently, many researchers on prose comprehension have used propositional analysis for representing the content of prose materials. This method involves preparing a relatively formal representation of the semantic content of the material, expressed in the form of a list of propositions. This representation can then be used as a relatively rigorous characterization of the material, and so serves as a basis for evaluating and analyzing readers' performance in comprehension experiments. This report presents a set of detailed rules and examples for constructing the propositional representation of both the textual ma-

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Abstract

Recently, many researchers on prose comprehension have used propositional analysis for representing the content of prose materials. This method involves preparing a relatively formal representation of the semantic content of the material, expressed in the form of a list of propositions. This representation can then be used as a relatively rigorous characterization of the material, and so serves as a basis for evaluating and analyzing readers' performance in comprehension experiments. This report presents a set of detailed rules and examples for constructing the propositional representation of both the textual materials used in, and subjects' responses from, experiments on comprehension of technical prose. Methods for using propositional analysis to score recall protocols and compare statements made by subjects are also described.

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1.0 INTRODUCTION.

Recently, many researchers on prose comprehension have used propositional analysis for representing the content of prose materials. This method involves preparing a relatively formal representation of the semantic content of the material, expressed in the form of a list of propositions. This representation can then be used as a relatively rigorous characterization of the material, and so serves as a basis for evaluating and analyzing readers' performance in comprehension experiments.

This report is a practical manual for the use of the propositional method of analyzing text, and scoring subject response protocols. The texts dealt with can be described as technical prose, rather than stories, and the response protocols dealt with are (1) gist recall protocols from prose memory experiments in which reproductive recall only is scored, and (2) responses produced in a "main idea" task, where after reading a passage the subject must produce a one-sentence statement of the "main idea". For recall protocols, the material to be "propositionalized" is normally a passage and the propositions form a scoring key. For comparing main idea responses, the responses are first propositionalized and then closely synonymous arguments and propositions are grouped together. This enables similarity in responses to be determined in a reasonably systematic and objective way.

The method described here was developed from Kintsch (1974), based mostly on the practical manual written by Turner and Greene (Note 1). However, our work led us to develop an approach that we felt was simpler and more oriented to experimental purposes than Turner and Greene's treatment. Their propositional analysis approach tended to focus on theoretical issues of semantics, and emphasized literary texts; but in our experience these matters have little relevance in the scoring of responses made in our experiments on memory and summarization of technical prose. This report is thus a summary of the rules and approaches that we developed from experience with the problems encountered dealing with actual text and subject responses. Therefore, apart from a few introductory examples, all the examples used are from actual texts and subject responses. It is hoped that other researchers will find this report useful in applying and further developing these methods.

2.0 REPRESENTATION OF PROPOSITIONS.

2.1 Format of Propositional Representation.

Although this method of constructing propositions from a text is not intended to be used by a computer simulation, the actual representation is intended to be readable by the LISP programming language. We have used a LISP program to read the proposition lists for subjects' main idea responses and then count similar propositions and arguments as an aid in the comparison process. Thus, there are some features of the format of the representation that are done purely because they enable LISP to use it.

An example will best illustrate the general method and format of this representation:

Ex 1: The fat cat ate the gray mouse.
P1 (EAT CAT MOUSE)
P2 (MOD CAT FAT)
P3 (MOD MOUSE GRAY)

The proposition P1 is a simple verb frame consisting of the predicate EAT and two arguments: the logical subject, the word concept CAT, and the logical object, the word concept MOUSE. P2 consists of the predicate MOD (modify) followed by two arguments, the word concepts CAT and FAT. The predicate of a proposition is always written first, followed by its arguments. Word concepts are capitalized to distinguish them from words and they are normally singular. Because, in Ex 1, the cat that is fat is the same cat that eats the mouse, the same word concept is used. If there were two cats in the sentence, they would have to be distinguished:

Ex 2: The black cat and the gray cat ...
P1 (MOD CAT1 BLACK)
P2 (MOD CAT2 GRAY)

Predicates and arguments are separated by spaces and the whole proposition enclosed in parentheses. Each proposition is labelled with a number to make individual propositions easy to refer to. Since LISP handles numbers in different ways from alphanumeric symbols, all numbers, including proposition labels, are preceded by a letter character to force LISP to treat them as symbols. For numbering propositions this is done with the letter "P", as shown in the examples. For numerical arguments, the prefix is "N" so that 150,000 would be represented as N150000 (the comma should not appear if LISP is used). Alternatively the number can be written out so that 2 would be represented as TWO.

Arguments for a predicate can be either word concepts or other propositions.

Ex 3: The cat quickly ate the mouse.
P1 (EAT CAT MOUSE)
P2 (MOD P1 QUICK)
OR
P1 (EAT CAT MOUSE)
P2 (MOD (EAT CAT MOUSE) QUICK)

Here the first argument to the predicate MOD is the P1 proposition. It is, of course, far more convenient to refer to a proposition by its label than to write it out in its entirety each time it is used.

Finally, because LISP treats spaces as string separators, when two words are used together as a single argument, they must be joined by a hyphen.

Ex 4: ice cream parlor.
P1 (MOD PARLOR ICE-CREAM)

2.2 Normal Order of Arguments.

As we have seen, the predicate of a proposition is represented first and the arguments to the predicator follow. The order in which the arguments are shown is important: (EAT CAT MOUSE) and (EAT MOUSE CAT) should represent different things.

The rule that we have used is that the predicate should be interpreted as being after the first argument. For most propositions, which have two arguments, this means that the predicate can be thought of as operating between the arguments.

Some examples will illustrate this:

Ex 1: (EAT CAT MOUSE)
Interpreted as: cat eats mouse.

Ex 2: (EAT MOUSE CAT)
Interpreted as: mouse eats cat

Ex 3: (MOD CAT BLACK)
Interpreted as: cat modified by black.

The correct ordering of arguments is particularly important when the predicate is a word like <u>because</u>. This is because it must be clear in the proposition which argument is cause and which effect.

Ex 4: Because B is true, A is true.
P1 (BECAUSE A-TRUE B-TRUE)
Interpreted: A-true because B-true.

2.3 Practical Considerations of Representation.

Some general rules can be stated for constructing propositional representations of prose material. These rules are justified by their practical effect on using propositional scoring. Specific cases of these rules show up in the detailed treatment below. Our practice is that, where helpful, we sacrifice technical accuracy of representation for simplicity and ease of construction and use of the representation.

1. When there are several reasonable ways to represent the text, choose the simplest.

2. Try to avoid embedding; non-embedded representations are simpler to work with, and simplify scoring.

3. Avoid unnecessary propositions by representing compound nouns as a single term. For example, terms such as X-ray star can often be represented as a single term, X-RAY-STAR, rather than by multiple modification of STAR. In the case of black hole, it is clear why this is useful: a black hole in the astronomical sense is not simply a hole that is black. Hence:

Ex 1: X-ray stars are black holes.
P1 (ISA X-RAY-STAR BLACK-HOLE)

4. Try to avoid unnecessary variants of terms; for example, use QUICK instead of both QUICK and QUICKLY.

5. Invent predicate terms freely where they result in a simpler representation and correspond to a common structure. For example, don't attempt to analyze complex common verbs forms into their constituent propositions. Instead form a single term, so that know how to would be represented simply as KNOW-HOW-TO. We also invented the predicate EXTENT-OF to represent a confusing variety of expressions about size, length and so forth.

6. Where possible, fully propositionalize experimental text material before it is used, so that it can be modified to produce simpler representations that will be easier to score.

7. For recall experiments, choose representations that will reflect partial or paraphrased recall most easily.

Ex 1: Radio galaxies emit radio waves.
P1 (EMIT GALAXY WAVE)
P2 (MOD GALAXY RADIO)
P3 (MOD WAVE RADIO)
not
P1 (EMIT RADIO-GALAXY RADIO-WAVE)

The first representation shown allows one to distinguish recall that preserves the "radio" modification from those that don't.

However, for comparing summarization responses, minimizing the number of propositions and embedding them will eliminate many unimportant differences between responses and so faciliatate determining the similarities and important differences.

3.0 CONSTRUCTION OF PROPOSITIONS.

3.1 Verb-based Propositions.

3.1.1 Representation of Ordinary Verbs. - These propositions are normally formed from the main verb of a clause, but they are also formed from participles and infinitives.

Our representation system, like the original Kintsch (1974) proposal, is based on a case grammar representation for verb-based propositions. However, we have found that almost all of the detailed analysis of case assignments presented in Kintsch (1974) and Turner and Greene (Note 1) is not really necessary for the practical purposes of scoring recall or comparing responses. As a result, our methods emphasize representing the propositional content in as simple a way as possible.

In this system, verb predicates are represented by the infinitive form of the verb. Tenses are disregarded, and auxiliaries are not represented.

Verbs have a case structure that can be, in some instances, fairly complex. For example, the verb call has cases for the person or thing that assigns the name, the person or thing that is named, and the name given.

Ex 1: Scientists call the radio galaxy DA240.
P1 (CALL SCIENTIST RADIO-GALAXY DA240)

Ex 2: The radio galaxy is called DA240 by scientists.
P1 (CALL SCIENTIST RADIO-GALAXY DA240)

In both examples, the scientists are performing the act of calling (or naming) on the radio galaxy, while DA240 is the name used in the action. The passive construction, shown in Ex 2, does not change the case grammar of the verb: the same things are happening to the same people and things. Thus, when propositionalizing, passive constructions are represented in the same way as their equivalent active construction.

In this method, a fairly simple case structure is used for verbs and they preferably take two cases, although some take one, and a few take three. Whenever possible only two cases are used: the logical subject and the logical object.

Ex 3: Devices have existed ...
P1 (EXIST DEVICE)

Ex 4: Asteroids have affected the evolution of planets.
P1 (AFFECT ASTEROID EVOLUTION)
etc.

Sometimes, although the verb naturally takes two cases, no argument is supplied in the text. This missing argument is denoted by the placeholder $.

Ex 5: Metals are used.
P1 (USE $ METAL)

Finally, unlike many other case grammar approaches, we do not complicate the representation by insisting on distinguishing animate actors from inanimate ones.

3.1.2 Verbs with Prepositions. - The common use in English of verbs which take prepositions tends to be confusing in a case grammar approach. The preposition itself is variable; it can be one of several alternatives, or it could be absent entirely. The simplest way to deal with such forms is to consider the preposition as a part of the verb itself: for example, DIFFER-IN, ADVANCE-WITH. This representation avoids unnecessary embedding of propositions and is also clear and unambiguous. Ex 1 and Ex 2 illustrate the great difference in meaning that a preposition can cause, and how easily this difference can be represented.

Ex 1: Metal technology has advanced civilization.
P1 (ADVANCE TECHNOLOGY CIVILIZATION)
etc.

Ex 2: Metal technology has advanced with civilization.
P1 (ADVANCE-WITH TECHNOLOGY CIVILIZATION)
etc.

The presence or absence of a preposition does not always change the meaning, and this can lead to a problem in representation. Consider these examples:

Ex 3: Clocks differ in accuracy.

Ex 4: Cars differ and so ...

In Ex 3, the verb predicate would be DIFFER-IN. The preposition is represented as an explicit part of the verb because this is clearer. In Ex 4, either DIFFER-IN or DIFFER could be used as the predicate.

Ex 3: Clocks differ in accuracy.
P1 (DIFFER-IN CLOCK ACCURACY)

Ex 4: Cars differ and so ...
P1 (DIFFER CAR)
etc.
OR
P1 (DIFFER-IN CAR $)
etc.

3.1.3 Verbs that take Verbs. - Verbs often have a double structure, where the first verb takes a second verb. For example, the verbs to tend to and to continue to both take a second verb. This is most simply represented with two propositions:

Ex 5: People tend to use cars frequently.
P1 (TEND-TO PEOPLE P2)
P2 (USE PEOPLE CAR)
etc.

Ex 6: Cars continue to be used by most people.
P1 (CONTINUE-TO PEOPLE P2)
P2 (USE PEOPLE CAR)
etc.

In both these examples the prepositional part of the verb is explicitly represented. This explicit representation will avoid possible confusion like that between to tend to and to tend in the sense of to look after.

Other two-verb constructions can be handled in the same way:

Ex 7: Metals can be used in many ways.
P1 (ABLE-TO $ P2)
P2 (USE $ METAL)

Ex 8: Scientists know how to classify X-ray stars.
P1 (KNOW-HOW-TO SCIENTIST P2)
P2 (CLASSIFY SCIENTIST X-RAY-STAR)

Here can is treated as part of the verb to be able and to know how to is treated as a single verb analogous to the French savoir.

3.1.4 Propositions as Arguments. - Some verbs take propositions as arguments, although they do not have the double structure described above. This is often expressed in English by a that clause.

Ex 1: Astronomers think that X-ray stars are black holes.
P1 (THINK ASTRONOMER P2)
P2 (ISA X-RAY-STAR BLACK-HOLE)

3.1.5 Verbs as Participles. - Verb participles are often found that are not part of the main verb of a clause. They are propositionalized using the infinitive form of the verb.

Ex 1: Humans have detected flashes containing five quanta of light.
P1 (DETECT HUMAN FLASH)
P2 (CONTAIN FLASH QUANTUM)
etc.

3.1.6 May - The verb may could be propositionalized in two ways: by analogy with can as above (see Sec. 3.1.3, Ex 7), or as equivalent to the adverb possible. The second method is the one that we prefer.

Ex 1: Asteroids may affect planets.
P1 (AFFECT ASTEROID PLANET)
P2 (MOD P1 POSSIBLE)

3.1.7 Have. - Have in a sentence needs care because it has several possible uses and is propositionalized differently, depending on the use. Thus, we never use HAVE as a predicate. Sometimes it is merely an auxiliary and can be disregarded:

Ex 1: Metals have been used by many cultures.
P1 (USE CULTURE METAL)
etc.

Have can also be part of a compound, such as to have to. Have to means must or necessary, and is better propositionalized as one of these forms:

Ex 2: Nixon had to resign.
P1 (MUST NIXON P2)
P2 (RESIGN NIXON)
OR
P1 (MOD P2 NECESSARY)
P2 (RESIGN NIXON)

Have can also indicate possession:

Ex 3: Metals have many uses.
P1 (POSSESS METAL USE)
etc.

3.1.8 To Be. - When the main verb is a form of the verb to be, then there are three possible propositionalizations, depending on the structure:

If the structure is:

NOUN1 is a NOUN2

OR

NOUN1 is the NOUN2

an ISA or REF proposition, respectively, is formed (see Ex 1 and Ex 2 below).

If the structure is:

NOUN is ADJECTIVE

then a MOD proposition is formed (see Sec. 3.2.1 below).

REF can be thought of as meaning is the and is used to indicate that one thing is the same as another (has the same REFerent). SAME-AS would be an alternative predicate.

Ex 1: The corona is the outer atmosphere of the sun.
P1 (REF CORONA ATMOSPHERE)
etc.
OR
P1 (SAME-AS CORONA ATMOSPHERE)
etc.

ISA is used to denote membership of the first argument in the set defined by the second:

Ex 2: A piano is a keyboard instrument.
P1 (ISA PIANO INSTRUMENT)
etc.

3.1.9 Become. - This verb can cause a few problems in propositionalization. The case grammar of become is such that it demands two arguments, the first of which is normally a noun. The second can also be a noun, in which case the propositionalization is simple:

Ex 1: Microprocessors have become the workhorses of industry.
P1 (BECOME MICROPROCESSOR WORKHORSE)
etc.

Occurrences where the second argument is adjectival have two possibilities for propositionalization:

Ex 2: Clocks have become very accurate.
Method 1:
P1 (BECOME CLOCK ACCURATE)
etc.
Method 2:
P1 (BECOME CLOCK P2)
P2 (MOD CLOCK ACCURATE)
etc.

There seems to be no advantage of method 2 over method 1. Method 2 is clumsier, uses unnecessary embedding and, compared with method 1, is not particularly clear.

3.2 Representation of Modifiers.

3.2.1 Modification. - Modifiers, in the limited definition used here, are normally adjectives and adverbs that modify nouns or verbs. Some examples of modifier propositions have already been used in this report:

Ex 1: Fat cat...
P1 (MOD CAT FAT)

The object of modification can be a noun (adjectival modification) or a proposition (adverbial modification).

Ex 2: Keyboard instrument.
P1 (MOD INSTRUMENT KEYBOARD)

Here KEYBOARD is an adjectival modification of INSTRUMENT. Although keyboard is a noun, English permits this type of construction.

In English, adjectival modification is often expressed with the verb to be:

Ex 3: Cars are popular.
P1 (MOD CAR POPULAR)

In adverbial modification, the adverb modifies the verb. For convenience, but at the sacrifice of technical accuracy, this is represented as modification of the whole verb proposition.

Ex 4: The control was greatly improved.
P1 (IMPROVE $ CONTROL)
P2 (MOD P1 GREAT)

3.2.2 Multiple Modification. - Multiple modification is represented without embedding of propositions. Thus, in Ex 1, sophisticated is not a modification of modern clock but of clock.

Ex 1: Sophisticated modern clocks ...
P1 (MOD CLOCK MODERN)
P2 (MOD CLOCK SOPHISTICATED)

Sometimes multiple modifications are made up of modifiers that are actually single concepts:

Ex 2: Quartz crystal watches ...

Based on Ex 1 above, one might think that this should be propositionalized as:

P1 (MOD WATCH CRYSTAL)
P2 (MOD WATCH QUARTZ)

However, the watches are not quartz watches that are also crystal watches. A better representation might be:

P1 (MOD WATCH CRYSTAL)
P2 (MOD CRYSTAL QUARTZ)

But since we prefer simple structures, we prefer not to divide up modifications too finely. The actual modification is that the watch is of a certain type, a quartz-crystal type. Thus, the preferred propositionalization is:

P1 (MOD WATCH QUARTZ-CRYSTAL)

3.2.3 Negation. - Propositions are negated by means of the NEGATE predicate. NEGATE has one argument and this argument is always a proposition.

Ex 1: The speed is not constant.
P1 (MOD SPEED CONSTANT)
P2 (NEGATE P1)

Sometimes, there can be a question as to exactly which proposition is being negated. This can only be decided by careful consideration of the meaning.

Ex 2: The players did not play chess carelessly.
P1 (PLAY PLAYER CHESS)
P2 (MOD P1 CARELESS)
P3 (NEGATE P?)

The question here is whether the negation should be of P1 or P2. The meaning of this sentence is not that the players did not play chess, rather that they did play but not carelessly. Therefore the negation is of P2, not P1.

3.2.4 Time. - Some propositions place their first argument into a time frame. These are time propositions and are commonly represented in one of two ways. The first uses the predicate TIME and the second DURATION-OF. TIME is used when a proposition or word concept is given a reference to a particular point in time. DURATION-OF is used when an action is described as being over some period of time.

Ex 1: A natural nuclear reactor was active in the Precambrian era for many years.
P1 (MOD REACTOR ACTIVE)
P2 (TIME P1 PRECAMBRIAN-ERA)
P3 (DURATION-OF P1 YEAR)
etc.

The Precambrian era is the point in time when the reactor was active and so a TIME proposition is used. The reactor was also active over the period of many years and so a DURATION-OF proposition should be used.

Ex 2 shows that not only propositions can be put into a time frame. Here there are two types of chess player, from two different times.

Ex 2: Today's chess players are better than players of the 19th century.
....
P2 (TIME PLAYER1 TODAY)
P3 (TIME PLAYER2 N19TH-CENTURY)

3.2.5 Label. - Compound proper names present difficulties in propositionalization. Simple proper names can be used as arguments with no problem:

Ex 1: John hit Mary.
P1 (HIT JOHN MARY)

But consider:

Ex 2: The British won the Battle of Jutland.

Ex 3: Hydrogen maser clocks are used by the National Bureau of Standards.

In these two examples it is senseless to attempt to propositionalize the names: the Battle of Jutland is the name of a particular battle and the relationship between battle and Jutland is not a modification or possession relationship. Similarly the National Bureau of Standards is the name of a particular bureau. In these circumstances, the LABEL predicate is useful. It assigns to an ordinary noun a particular name.

Ex 2: The British won the Battle of Jutland.
P1 (WIN BRITISH BATTLE)
P2 (LABEL BATTLE BATTLE-OF-JUTLAND)

Ex 3: Hydrogen maser clocks are used by the National Bureau of Standards.
P1 (USE BUREAU CLOCK)
P2 (LABEL BUREAU NATIONAL-BUREAU-OF-STANDARDS)
P3 (MOD CLOCK HYDROGEN-MASER)

P3 in Ex 3 is not represented with a LABEL predicate because hydrogen maser clock is a type of clock rather than a proper name for a particular clock.

3.3 Representation of Prepositions.

3.3.1 Prepositions as Predicates. - Prepositions take two arguments: the second is almost always a noun while the first can be a noun or a proposition.

Ex 1: Metals have been used for many purposes.
P1 (USE $ METAL)
P2 (FOR P1 PURPOSE)
etc.

Ex 2: People in the United States like cars.
P1 (LIKE PEOPLE CAR)
P2 (IN PEOPLE UNITED-STATES)

In Ex 2, P2 was not propositionalized as:

(IN P1 UNITED-STATES)

because the people are what is in the United States, not the act of liking cars.

Some prepositions, such as between, can take three arguments, instead of the normal two for prepositions. For between, this is because one thing is usually between two other things.

Ex 3: The Battle of Jutland was between the Germans and the British.
P1 (BETWEEN BATTLE GERMAN BRITISH)
etc.

3.3.2 Prepositions that are part of Connectives. - When an apparent preposition has propositions for both arguments, it is probably a connective: for example, to for IN-ORDER-TO, for for IN-ORDER-FOR (see Sec. 3.9.3 below).

Ex 1: Microprocessors are used to improve many devices.

The to in this example means in order to and is propositionalized as a connective.

3.3.3 Prepositions that should disappear. - Sometimes, a structure that uses a preposition is more conveniently considered as a verb. Thus, the preposition may not appear in the representation.

Ex 1: The Battle of Jutland was a suprise to the British.

Possible propositionalization:

P1 (REF BATTLE SUPRISE)
P2 (TO SUPRISE BRITISH)
P3 (LABEL BATTLE BATTLE-OF-JUTLAND)

Better propositionalization:

P1 (SUPRISE BATTLE BRITISH)
P2 (LABEL BATTLE BATTLE-OF-JUTLAND)

The actual word use is changed in the better version in that suprise is used as a verb rather than as a noun, but the "better" version is neater, simpler, and more easily worked with.

3.4 Propositions that express Quantity.

3.4.1 Number-of. - Number can be definite or indefinite. A definite quantity is expressed by an actual number, while an indefinite quantity is expressed by words such as several, all or most. Many number propositions use the predicate NUMBER-OF:

Ex 1: There are three prototypes.
P1 (EXIST PROTOTYPE)
P2 (NUMBER-OF PROTOTYPE THREE)

Ex 2: Most people ...
P1 (NUMBER-OF PEOPLE MOST)

Ex 3: Hundreds of people ...
P1 (NUMBER-OF PEOPLE HUNDREDS)
OR
P1 (NUMBER-OF PEOPLE HUNDRED)
P2 (NUMBER-OF HUNDRED SOME)

The first method shown in Ex 3 is clearest.

3.4.2 Amount-of. - Another predicate used for number is AMOUNT-OF. This is used similarly to NUMBER-OF when NUMBER-OF or MOD are inappropriate. This representation is very useful for quantities such as all of or half of.

Ex 3: The portal vein carries all the blood from the intestines.
P1 (CARRY VEIN BLOOD)
P2 (AMOUNT-OF BLOOD ALL)
etc.

3.4.3 Rate-of. - In technical prose, various measurements are often expressed as rates of one kind or another. Such rates are very difficult to propositionalize using NUMBER-OF or AMOUNT-OF. In this sort of case, the RATE-OF predicate is useful:

Ex 1: The car is travelling at sixty miles per hour.
P1 (TRAVEL CAR)
P2 (RATE-OF P1 MILES-PER-HOUR)
P3 (NUMBER-OF MILES-PER-HOUR SIXTY)

3.4.4 Degree-of. - The use of DEGREE-OF for measurement is illustrated by:

Ex 1: Clocks today are accurate to one second in a million years.
P1 (MOD CLOCK ACCURATE)
P2 (TIME CLOCK TODAY)
P3 (DEGREE-OF P1 ONE-SECOND-PER-MILLION-YEAR)

This would be the simplest method, but an alternative representation would be:

P3 (DEGREE-OF P1 SECOND-PER-YEAR)
P4 (NUMBER-OF SECOND ONE)
P5 (NUMBER-OF YEAR MILLION)

Both methods have their advantages; the first would be most useful for comparing subject responses, while the second would be better for a recall scoring key.

DEGREE-OF can also represent indefinite values:

Ex 2: Modern clocks have incredible accuracy.
P1 (POSSESS CLOCK ACCURACY)
P2 (MOD CLOCK MODERN)
P3 (DEGREE-OF ACCURACY INCREDIBLE)

Of course, P3 could also be represented using a MOD proposition. For recall scoring, MOD would be adequate but for comparing subject responses DEGREE-OF would be better as it helps make the similarity of examples 1) and 2) more obvious.

3.5 Part-whole Relations and Possession.

This section illustrates our approach of ignoring niceties of the semantics in favor of simple straightforward representations. Our treatment of part-whole and possession relations is easy to apply, but ignores some of the difficulties grappled with by Turner and Greene(Note 1).

The predicate PART-OF can be used to represent the part-whole relation. In general terms:

PART-OF PART WHOLE

This is most useful when the part-whole relationship is explicit in the text:

Ex 1: The corona is part of the sun.
P1 (PART-OF CORONA SUN)

Possessive forms in English can be confusing because of the looseness of the concept of possession. Our system uses POSSESS very loosely to simplify the representation.

Ex 2: The sun has a corona.

This is not very different in meaning from Ex 1 but would be propositionalized:

P1 (POSSESS SUN CORONA)

Many times <u>of</u> can be interpreted as meaning possession.

Ex 3: The properties of metals have been valued by many cultures.
P1 (VALUE CULTURE PROPERTY)
P2 (POSSESS METAL PROPERTY)
etc.

This would be the same propositionalization as for:

Ex 4: Many cultures have valued metals' properties.

or

Ex 5: Metals have properties that have been valued by many cultures.

Thus <u>of</u> can frequently be considered as an alternative construction to <u>have</u> and can be propositionalized using POSSESS. However, <u>of</u> can be used for many different purposes, and care needs to be taken in defining these (see below in section 4.5).

3.6 Superlatives.

Superlative forms are considered simply as adverbs and adjectives and thus they use a MOD construction. Superlatives that are constructed using most are represented with most as an adverb. Superlatives with special forms like best are treated as simple adjectives:

Ex 1: The car is the most popular form of transportation.

```
....
P2 (MOD FORM POPULAR)
P3 (MOD P2 MOST)
....
```

Ex 2: The car is the best form of transportation for most people.

```
....
P2 (MOD FORM BEST)
P3 (FOR FORM PEOPLE)
P4 (NUMBER-OF PEOPLE MOST)
```

Ex 2 shows that most can be either the superlative, propositionalized using MOD, or a quantity, propositionalized using NUMBER-OF (Sec. 3.4.1).

3.7 Comparatives.

There are a large number of comparative constructions. These include: more something than, better than, different from and as something as. Most compare two things along some dimension; sometimes the dimension is explicit, as in more accurate than, and sometimes not, as in compare to. Rather than attempting to represent the subtle semantic structure of a comparative, we use a rather simple form:

Ex 1: The piano is better than the harpsichord.

```
P1 (BETTER-THAN PIANO HARPSICHORD)
```

Ex 2: The piano is different from the harpsichord.

```
P1 (DIFFERENT-FROM PIANO HARPSICHORD)
```

Some comparatives could be propositionalized in two ways:

Ex 3: The piano is more expressive than the harpsichord.
Method 1:

```
P1 (MORE-THAN P2 P3)
P2 (MOD PIANO EXPRESSIVE)
P3 (MOD HARPSICHORD EXPRESSIVE)
```

Method 2:

P1 (MORE-EXPRESSIVE-THAN PIANO HARPSICHORD)

Method 2 treats more expressive than as a single relation between the two arguments. It is most useful when comparing subject responses with each other. Method 1, on the other hand, is most useful when scoring recall protocols because a subject could get credit for recalling only that the piano is expressive even though the other parts of the relationship are not recalled. If method 2 was used, that subject would not get any credit at all.

3.8 Questions.

Questions do not usually appear in the descriptive prose which has been the material in our work. However, subjects will sometimes respond using questions. Question predicates have one argument which is always a proposition.

Ex 1: How did a nuclear reactor occur naturally?
P1 (HOW P2)
P2 (OCCUR REACTOR)
etc.

Ex 2: The passage described how people have used metals.
P1 (DESCRIBE PASSAGE P2)
P2 (HOW P3)
P3 (USE PEOPLE METAL)

What tends to be clumsy to propositionalize in whatever way it is done. One way is to treat it exactly like other question words:

Ex 3: What is an X-ray star?
P1 (WHAT P2)
P2 (ISA X-RAY-STAR $)

Ex 4: Scientists do not know what X-ray stars are.
P1 (KNOW SCIENTIST P3)
P2 (NEGATE P1)
P3 (WHAT P4)
P4 (ISA X-RAY-STAR $)

3.9 Connectives.

3.9.1 Logical Connectives. - There are two main logical connectives. They are: AND and OR. Both express a logical relationship between two propositions.

Frequently in text, and (and sometimes or) is used to string together a list. In such cases, the and is a purely linguistic device and has no logical content. We propositionalize such sentences just as if they consisted of several separate sentences, with the and not even appearing in the representation:

Ex 1: Different metals have various strengths, uses and values.
P1 (POSSESS METAL STRENGTH)
P2 (POSSESS METAL USE)
P3 (POSSESS METAL VALUE)
etc.

Ex 2: The piano is more expressive than the clavichord or the harpsichord.
P1 (MORE-EXPRESSIVE-THAN PIANO CLAVICHORD)
P2 (MORE-EXPRESSIVE-THAN PIANO HARPSICHORD)

Ex 3: The piano is more expressive than the clavichord and the harpsichord.
P1 (MORE-EXPRESSIVE-THAN PIANO CLAVICHORD)
P2 (MORE-EXPRESSIVE-THAN PIANO HARPSICHORD)

In cases such as these examples, one is tempted to further simplify the representation by defining a set of terms, and then apply a proposition to the set. For example, Ex 1 above could be represented as:

P1 (SET-MEMBERS STRENGTH USE VALUE)
P2 (POSSESS METAL P1)

However, the simplicity of this representation is deceptive. In attempting to score recall protocols there is no obvious criterion for when to score P1 as recalled if only some of the terms are recalled. The method used in Ex 1, however, always produces well-defined scoring if only some of the terms appear in recall.

Occasionally, and and or are used not just as grammatical devices but in ways corresponding to the actual logical content. For example, in Ex 4, both the propositions connected by and must be true in order for the last to be true. This is a logical AND and must be propositionalized. Synonyms for and include both and as well as. An exclusive or should be propositionalized, while inclusive or would not need to be. The either...or in Ex 5

is an exclusive OR. Or alone can be inclusive or exclusive and care should be taken to decide which it is.

Ex 4: If a woman is RhD negative and her fetus is RhD positive, she may develop RhD antibodies.

```
...
P2 (MOD WOMAN RHD-NEGATIVE)
P3 (MOD FETUS RHD-POSITIVE)
P4 (AND P2 P3)
      etc.
```

Ex 5: X-ray stars are either black holes or neutron stars.

```
P1 (OR P2 P3)
P2 (ISA X-RAY-STAR BLACK-HOLE)
P3 (ISA X-RAY-STAR NEUTRON-STAR)
```

3.9.2 Propositional Connectives. - One group of connectives is usually found in a sentence linking together two main clauses. They include: although, because, if, and in order to. The propositions linked by these connectives are the verb propositions of the clauses.

Ex 1: The Battle of Jutland was a strategic victory for the British, although the Germans won tactically.

```
P1 (ALTHOUGH P2 P4)
P2 (REF BATTLE VICTORY)
P3 (LABEL BATTLE BATTLE-OF-JUTLAND)
P4 (WIN GERMAN BATTLE)
P5 (MOD P4 TACTICAL)
```

Ex 2: Because keyboard instruments vary, the performer can control the sound.

```
P1 (BECAUSE P4 P2)
P2 (VARY INSTRUMENT)
P3 (MOD INSTRUMENT KEYBOARD)
P4 (ABLE PERFORMER P5)
P5 (CONTROL PERFORMER SOUND)
```

Ex 3: If a quartz crystal watch is adjusted properly, it is extremely accurate.

```
P1 (IF P5 P2)
P2 (ADJUST $ WATCH)
P3 (MOD P2 PROPER)
P4 (MOD WATCH QUARTZ-CRYSTAL)
P5 (MOD WATCH ACCURATE)
P6 (MOD P5 EXTREME)
```

Ex 4: Different cars have been developed in order to meet different needs.

```
P1 (IN-ORDER-TO P2 P4)
P2 (DEVELOP $ CAR)
P3 (MOD CAR DIFFERENT)
P4 (MEET CAR NEED)
```

P5 (MOD NEED DIFFERENT)

A second group of connectives is those that link clauses and whole sentences with material that was presented earlier. This group includes thus, therefore, and however. Sometimes the earlier material referred to will be simply earlier in the same sentence, but more frequently, it will be in a previous sentence. The arguments to these predicates are connective propositions or, if there are no connectives, verb-based propositions.

Ex 1: The Incas valued gold because they used it in religious ceremonies. However, the Spaniards wanted it for monetary reasons.

```
P1 (BECAUSE P2 P3)
P2 (VALUE INCA GOLD)
P3 (USE INCA GOLD)
P4 (IN P3 CEREMONY)
P5 (MOD CEREMONY RELIGIOUS)
P6 (HOWEVER P1 P7)
P7 (WANT SPANIARD GOLD)
P8 (FOR P7 REASON)
P9 (MOD REASON MONETARY)
```

It may be found useful, when propositionalizing a long text, to preserve the original sentence boundaries. This can be represented with an extra label on the propositions.

```
S1:P1 (BECAUSE P2 P3)
   P2 (VALUE INCA GOLD)
   P3 (USE INCA GOLD)
   ....
S2:P1 (HOWEVER S1:P1 S2:P2)
   P2 (WANT SPANIARD GOLD)
```

There is another group of connectives that is like the second group described above in that these connectives link current material to that in previous sentences. However, they use a short phrase like This means that ... rather than a single word. These phrases are represented using the single predicate that is the closest in meaning to the phrase: for example, this means that can be represented by IMPLY, and this results in can be represented by CAUSE.

Ex 1: Travel by aiplane is very expensive. This means that people tend to use airplanes only for occasional long trips.

```
S1:P1 (MOD TRAVEL EXPENSIVE)
   P2 (MOD P1 VERY)
   P3 (BY TRAVEL AIRPLANE)

S2:P1 (IMPLY S1:P1 P2)
```

P2 (TEND-TO PEOPLE P3)
P3 (USE PEOPLE AIRPLANE)
P4 (FOR P3 TRIP)
P5 (MOD P4 ONLY)
P6 (MOD TRIP OCCASIONAL)
P7 (MOD TRIP LONG)

A final group of predicates can be considered connectives because they are often ordinary connectives used in this particular way. Because can be just an ordinary connective linking two propositions:

Ex 1: Because the mechanisms of keyboard instruments differ, the player has varying control over the sound.
P1 (BECAUSE P3 P2)
P2 (DIFFER MECHANISM)
P3 (POSSESS PLAYER CONTROL)
etc.

For the sake of simplicity, we sometimes use because to connect a proposition with a single argument. Usually, we distinguish this from BECAUSE by using BECAUSE-OF:

Ex 2: The player can control sound differently on different instruments because of their different mechanisms.
P1 (BECAUSE-OF P2 MECHANISM)
P2 (ABLE PLAYER P3)
P3 (CONTROL PLAYER SOUND)
etc.

3.9.3 Contracted Connectives. - Because our method of propositionalization does not attempt to classify connectives, problems can arise in the representation of words like to and for. When these words have propositions as arguments they are acting as connectives and it is useful to distinguish such use from a prepositional use. For example, consider to in the following:

Ex 1: Microprocessors are used to improve many devices.

The meaning of to here is the same as if the sentence were:

Ex 2: Microprocessors are used in order to improve many devices.

Thus the to in Ex 1 may be considered a contraction of in-order-to and the propositionalization of both examples would be:

P1 (IN-ORDER-TO P2 P3)
P2 (USE $ MICROPROCESSOR)
P3 (IMPROVE MICROPROCESSOR DEVICE)
etc.

3.10 Miscellaneous Constructions.

3.10.1 Pronouns. - When propositionalizing pronouns the actual word concept referred to must be inferred. This is, of course, what normally happens in reading.

Ex 1: Cultures have many uses for their metals.
P1 (POSSESS CULTURE USE)
P2 (FOR P1 METAL)
P3 (POSSESS CULTURE METAL)

It is inferred that the possessive pronoun refers to cultures.

3.10.2 Exist. - The EXIST predicate can be used in two ways: the first is to represent the verb exist, and the second is to represent the there is a ... construction. Ex 1 below shows the use of EXIST to represent exist. In Ex 3, note that there are ... can be ignored so that the propositionalization is the same as for Ex 2. Alternatively the EXIST predicate can be used.

Ex 1: Clocks have existed for centuries.
P1 (EXIST CLOCK)
P2 (DURATION-OF P1 CENTURIES)

Ex 2: Many clocks are used today.
P1 (USE $ CLOCK)
P2 (NUMBER-OF CLOCK MANY)
P3 (TIME P1 TODAY)

Ex 3: There are many clocks that are used today.
P1 (USE $ CLOCK)
P2 (NUMBER-OF CLOCK MANY)
P3 (TIME P1 TODAY)

OR

P1 (EXIST CLOCK)
P2 (NUMBER-OF CLOCK MANY)
P3 (USE $ CLOCK)
P4 (TIME P3 TODAY)

3.10.3 Example-of. - In technical prose, examples are frequently used. They can be represented using the predicate EXAMPLE-OF, whose first argument is an example of the second. As with many predicates already described, there are alternative ways to propositionalize text than to use EXAMPLE-OF, but such a use is recommended by its clarity and ease.

Ex 1: Hydrogen maser clocks are examples of modern timepieces.
P1 (EXAMPLE-OF CLOCK TIMEPIECE)
P2 (MOD CLOCK HYDROGEN-MASER)
P3 (MOD TIMEPIECE MODERN)

3.10.4 Appositional Phrases. - Appositional phrases are represented by REF or ISA.

Ex 1: One isomer, the 11-cis form, is converted to another isomer, the all-trans form.
P1 (CONVERT-TO $ ISOMER1 ISOMER2)
P2 (REF ISOMER1 FORM1)
P3 (MOD FORM1 N11-CIS)
P4 (REF ISOMER2 FORM2)
P5 (MOD FORM2 ALL-TRANS)

Ex 2: Cowpox, a mild disease, can prevent smallpox.
P1 (PREVENT COWPOX SMALLPOX)
P2 (ISA COWPOX DISEASE)
etc.

3.10.5 Idioms. - Idiomatic expressions are not used very often in the technical prose that we have studied, but they are fairly common in literary prose or in subject responses. It is often pointless to try to propositionalize an idiom as it stands and the therefore representation should normally be based on the meaning of the idiom.

Ex 1: Mary blew up.
P1 (BECOME MARY ANGRY)
P2 (MOD P1 SUDDEN)

Ex 2: It is hot today.
P1 (MOD WEATHER HOT)
P2 (TIME P1 TODAY)

Many expressions use an "It is ..." construction, as in Ex 2. The meaning of the expression should be determined and then propositionalized.

Ex 3: It is possible that asteroids have affected the

evolution of planets.
P1 (MOD P2 POSSIBLE)
P2 (AFFECT ASTEROID EVOLUTION)
etc.

Sometimes, an idiomatic phrase is best propositionalized exactly as it stands. This happens when the idiom has an unambiguous meaning and no simple non-idiomatic synonym. In Ex 4, all the way is an idiom that is best left as it stands.

Ex 4: Black moved his King's Bishop all the way across the board to capture material.
P1 (IN-ORDER-TO P2 P7)
P2 (MOVE BLACK BISHOP)
P3 (ACROSS P2 BOARD)
P4 (MOD P3 ALL-THE-WAY)
P5 (POSSESS BLACK BISHOP)
P6 (LABEL BISHOP KINGS-BISHOP)
P7 (CAPTURE BLACK MATERIAL)

4.0 SOME DIFFICULT PROBLEMS IN PROPOSITIONALIZATION.

4.1 Ambiguity.

There are two types of ambiguity found when propositionalizing a text. One type occurs when one word can have different functions. To as discussed in connectives (Sec. 3.9.3) is an example of this. When is another example since it can function both as a question and as a temporal connective. In both these cases, it is obvious how to propositionalize once the usage is determined.

The other kind of ambiguity is more difficult to resolve. It occurs when the text itself is ambiguous in meaning and thus the exact function of a word is hard to determine. One would hope that this kind of ambiguity would not exist in text used as an experimental material except by design. Thus when constructing a recall scoring key this should not be a problem. Propositionalizing a text before it is used is a good way to discover unintended ambiguity before presenting the text to subjects.

It is in subject responses that ambiguity is most likely to occur. Ambiguity can often be caused by subject's careless use of English. If a subject wrote the classic:

Ex 1: If the baby does not thrive on raw milk, boil it.

It would be pedantic to insist that it is ambiguous here. However, consider this subject's response:

Ex 2: X-ray stars have energy and gravity though it affects its partner more.

The meaning here is not obvious whichever way one decides to consider the two appearances of it. The context supplies important clues. The passage for which this was a response talked about the fact that X-ray stars have partner stars and so the possesive pronoun almost certainly represents X-ray star. Its partner could therefore be propositionalized:

P? (POSSESS X-RAY-STAR PARTNER)

However, the first it is still incomprehensible. One possible referent is X-ray star and this seems the most likely. If this were being scored for recall and there was a proposition about X-ray stars affecting their partners, one could safely assume that this was what the subject was trying to say. Otherwise one could do either of two things: represent the most likely meaning, or represent all possible meanings.

4.2 So Great That.

Ex 1: The thermal energy of the gas is so great that the sun cannot retain the corona.

For comparing subject responses to each other, a very surface oriented propositionalization is sufficient:

```
P1 (SO-GREAT-THAT ENERGY P2)
P2 (RETAIN SUN CORONA)
P3 (NEGATE P2)
   etc.
```

For a recall scoring key, it is easier if P1 is broken down into smaller units that are less surface-oriented. One proposition that can be easily extracted is:

```
P1 (MOD ENERGY GREAT)
```

The energy being great implies that the sun will not retain the corona

```
P2 (IMPLY P1 P3)
P3 (RETAIN SUN CORONA)
```

The emphatic quality of so could be represented by a DEGREE-OF proposition so the final propositionalization:

```
P1 (MOD ENERGY GREAT)
P2 (MOD ENERGY THERMAL)
P3 (DEGREE-OF P1 GREAT)
P4 (IMPLY P3 P5)
P5 (RETAIN SUN CORONA)
```

4.3 Some-other.

Ex 1: Some clocks are more accurate than others.

This very common construction is difficult to accurately propositionalize. A simple, but not entirely satisfactory method is:

```
P1 (MORE-ACCURATE-THAN CLOCK1 CLOCK2)
P2 (MOD CLOCK1 SOME)
P3 (MOD CLOCK2 OTHER)
```

4.4 Complex Set Constructions.

4.4.1 They both have the same number ... - Consider the following sentence:

Ex 1: Maleic acid and fumaric acid both have the same number of carbon, hydrogen and oxygen atoms.

This example is from a text that was to be used for a recall experiment. There is no obvious good way to represent it with propositions. Use of set constructions, mentioned above (see Sec. 3.9.1), might be useful here, but the result is extremely complex, and impractical to use for scoring. After struggling for some time, in this one case a special analysis of the sentence was used, based on idea units:

Idea unit	Propositions
A. Maleic acid and fumaric acid have atoms such that:	3
B. they have the same number of each type of atoms	3
C. A type of atom is carbon.	1
D. A type of atom is hydrogen.	1
E. A type of atom is oxygen.	1

Thus, a subject scored 3 propositions for recalling A, 3 more for recalling B and one each for C, D and E. This is not an ideal solution by any means but it served its purpose and was easy to use in practice. Our recommendation is to avoid using material that has these characteristics.

4.4.2 One of the ... - This very common construction has no really satisfactory method for propositionalization. Here are some of the ways we have done it:

Ex 1: An asteroid could destroy one of a planet's moons.

```
P1 (ABLE ASTEROID P2)
P2 (DESTROY ASTEROID MOON1)
P3 (ISA MOON1 MOON2)
P4 (NUMBER-OF MOON1 ONE)
P5 (POSSESS PLANET MOON2)
P6 (NUMBER-OF MOON2 SOME)
```

Ex 2: Five men were arrested for illegally entering the Watergate building, and one of them was James McCord Jr. who was head of security for the Committee to Re-Elect the President.

```
P1 (ARREST $ MAN1)
P2 (FOR P1 P3)
P3 (ENTER MAN1 BUILDING)
P4 (MOD P3 ILLEGAL)
P5 (NUMBER-OF MAN1 FIVE)
P6 (MOD BUILDING WATERGATE)
P7 (ISA MAN2 MAN1)
P8 (NUMBER-OF MAN2 ONE)
P9 (LABEL MAN2 JAMES-MCCORD-JR)
P10 (REF MAN2 HEAD-OF-SECURITY)
P11 (FOR HEAD-OF-SECURITY COMMITTEE)
P12 (LABEL COMMITTEE
        COMMITTEE-TO-RE-ELECT-THE-PRESIDENT)
```

4.4.3 The Strange Case of the Hypothetical Planet. - Here is another complex construction that demands a somewhat unusual representation.

Ex 1: If planets had evolved only by the accretion of particles, they would be more uniform than they are.

```
P1 (IF P6 P2)
P2 (EVOLVE PLANET2)
P3 (BY P2 ACCRETION)
P4 (MOD P3 ONLY)
P5 (OF ACCRETION PARTICLE)
P6 (MORE-UNIFORM-THAN PLANET2 PLANET1)
P7 (MOD PLANET2 HYPOTHETICAL)
P8 (EXIST PLANET1)
```

4.4.4 Growing Together. - Here there is another difficult to represent construction.

Ex 1: The fleets grew together in the mists of the North Sea, until finally the main battleship groups encountered each other.

```
P1 (UNTIL P2 P?)
P2 (GROW-TOGETHER FLEET)
P3 (NUMBER-OF FLEET TWO)
P4 (MOD P2 CLOSER)
P5 (IN P2 MIST)
P6 (POSSESS SEA MIST)
P7 (LABEL SEA NORTH-SEA)
P8 (ENCOUNTER-EACH-OTHER GROUP1 GROUP2)
P9 (ISA GROUP1 GROUP)
P10 (ISA GROUP2 GROUP)
P11 (MOD GROUP BATTLESHIP)
P12 (MOD GROUP MAIN)
```

P13 (MOD P8 FINALLY)

4.5 Of.

The simple word of is a very sophisticated word that has more than one role. The possession role was mentioned above (see Sec. 3.5). But consider:

Ex 1: Biotransformation causes the inactivation of drugs.

In this example, biotransformation is obviously the subject of the verb cause but the phrase the inactivation of drugs is somewhat difficult to represent. Of can be considered a meaning of POSSESS and so this sentence could be propositionalized:

P1 (CAUSE BIOTRANSFORMATION INACTIVATION)
P2 (POSSESS DRUG INACTIVATION)

POSSESS seems peculiar here because inactivation has a strong verb "flavor", although it is actually a noun. Another representation would be:

P1 (CAUSE BIOTRANSFORMATION P4)
P2 (INACTIVATE $ DRUG)

However, embedded propositions are always difficult to work with. In addition, this representation is clearly very different in meaning from the original. When the meaning of of is difficult to determine, the simple solution is to use it as a predicate itself and not worry about its exact meaning.

P1 (CAUSE BIOTRANSFORMATION INACTIVATION)
P2 (OF INACTIVATION DRUG)

5.0 EXAMPLE ANALYSIS OF A TEXT.

5.1 Procedure for Propositional Analysis of a Text.

The procedure for propositionalization can be shown as an algorithm:

I. Read the text through carefully.

II. For each sentence:
  1). Loosely parse into clauses.
  2). Pick out any connectives.
  3). For main clause (or first main clause):
    a). Represent main verb.
    b). Represent modifiers of predicate proposition.
    c). Represent modifiers to arguments of predicate proposition.
    d). Represent modifiers to other propositions or other arguments.
  4). Repeat a - d for any other clauses.

5.2 Example Analysis of a Text.

The example text, shown in Table 1, was used in a recall experiment. For psychological reasons the passage could not be modified to produce a simple representation, as we advised above (see Sec. 4.1). This extended example will illustrate in detail how the above rules and principles are applied to an extended piece of technical prose. The propositions for this example will be listed by sentence.

After reading through the text and ensuring that it is fully understood, examine the first sentence:

> S1:Biotransformation is the chemical transformation that causes the inactivation of drugs, the detoxification of environmental pollutants, and the deactivation of chemicals that can cause cancer.

There is a main clause and a compound subordinate clause. In the main clause, the verb is _is_. In this case, the _is_ is part of a _NOUN is the NOUN_ construction and should be represented with a REF predicate. The first argument is _biotransformation_ and the second is _transformation_. Thus:

S1:P1 (REF BIOTRANSFORMATION TRANSFORMATION)

There are no modifiers to this P1 proposition but one of the arguments is modified: the noun _transformation_ is decribed as _chemical transformation_ and so:

Table 1.

Text to be used for recall experiment.

Biotransformation is the chemical transformation that causes the inactivation of drugs, the detoxification of environmental pollutants and the deactivation of chemicals that can cause cancer. Biotransformation of harmful agents involves an oxidation reaction which is mediated by complex enzymes, and if this process does not take place, a drug entering the body may act indefinitely. Biotransformation defends the body against the effects of toxins and is carried out in the liver. The liver, weighing three pounds in the human adult, is the largest organ in the body and performs diverse functions. Through the large portal vein of the liver passes all the blood that has absorbed digested food and other substances from the intestines.

P2 (MOD TRANSFORMATION CHEMICAL)

Now the main clause is fully represented:

S1:P1 (REF BIOTRANSFORMATION TRANSFORMATION)
P2 (MOD TRANSFORMATION CHEMICAL)

The subordinate clause can be broken down into a list of sub-clauses, all of whose verb is cause. The first sub-clause is "that causes the inactivation of drugs". The subject of the verb is the relative pronoun that which represents transformation. Inactivation is the object of the verb and the simplest way to represent the phrase inactivation of drugs is to use OF as the predicate (see Sec. 4.5).

P3 (CAUSE TRANSFORMATION INACTIVATION)
P4 (OF INACTIVATION DRUG)

The second sub-clause is "that causes ... the detoxification of environmental pollutants". This is represented in a similar way to the first sub-clause except that an extra proposition must be added to represent the modification of pollutant.

P5 (CAUSE TRANSFORMATION DETOXIFICATION)
P6 (OF DETOXIFICATION POLLUTANT)
P7 (MOD POLLUTANT ENVIRONMENTAL)

The last sub-clause is itself a compound, containing a main and a relative clause. The main clause "that causes the deactivation of chemicals" is similar to the sub-clauses already propositionalized:

P8 (CAUSE TRANSFORMATION DEACTIVATION)
P9 (OF DEACTIVATION CHEMICAL)

In the relative clause, "that can cause cancer", the subject, that, refers to chemicals and so CHEMICAL will be the first argument of any verb propositions. The first verb is can which is represented by ABLE-TO with another proposition as second argument:

P10 (ABLE-TO CHEMICAL P11)

The second verb is cause and what the chemicals are able to do is to cause cancer. Thus:

P11 (CAUSE CHEMICAL CANCER)

So the final propositionalization of this sentence:

S1:P1 (REF BIOTRANSFORMATION TRANSFORMATION)
P2 (MOD TRANSFORMATION CHEMICAL)
P3 (CAUSE TRANSFORMATION INACTIVATION)
P4 (OF INACTIVATION DRUG)
P5 (CAUSE TRANSFORMATION DETOXIFICATION)
P6 (OF DETOXIFICATION POLLUTANT)
P7 (MOD POLLUTANT ENVIRONMENTAL)
P8 (CAUSE TRANSFORMATION DEACTIVATION)
P9 (OF DEACTIVATION CHEMICAL)
P10 (ABLE-TO CHEMICAL P11)
P11 (CAUSE CHEMICAL CANCER)

The second sentence is:

S2:Biotransformation of harmful agents involves an oxidation reaction which is mediated by complex enzymes, and if this process does not take place, a drug entering the body may act indefinitely.

Reading through this sentence it becomes clear that this is a compound sentence where two sentences have been combined into one by use of the and. This is not a logical and and so is not propositionalized as a connective. It seems easiest to treat the sub-sentences separately and the first is:

S2A:Biotransformation of harmful agents involves an oxidation reaction which is mediated by complex enzymes.

Here we have a main and a subordinate clause. In the main clause, the verb is involve whose subject is biotransformation and whose object is reaction. Thus:

S2:P1 (INVOLVE BIOTRANSFORMATION REACTION)

There are no modifiers to this proposition but both of the arguments are modified. The first argument is modified by of harmful agents. As in the first sentence this of phrase is a little unusual and the predicate used here is OF.

P2 (OF BIOTRANSFORMATION AGENT)

The second argument of P2 is modified and is most neatly represented next, to keep it separate from modifications to the second argument of P1.

P3 (MOD AGENT HARMFUL)

The second argument of P1, REACTION, is modified by an adjectival clause, "which is mediated by complex enzymes", and by the noun oxidation used as an adjective. The modification by oxidation comes first in the text and so:

P4 (MOD REACTION OXIDATION)

In the adjectival clause, the pronoun which represents reaction and the verb here is mediate. The verb is in passive form and the logical subject is enzyme since it is enzymes that are doing the mediating. What they are mediating is the reaction:

P5 (MEDIATE ENZYME REACTION)

ENZYME is modified by complex:

P6 (MOD ENZYME COMPLEX)

The second sub-sentence of the second sentence is:

S2B:If this process does not take place, a drug entering the body may act indefinitely.

Here there are two clauses joined by the conditional connective IF. The IF proposition is the highest level proposition and so is represented first. The appropriate arguments can be filled in later.

P7 (IF P? P?)

The first clause is "this process does not take place". The verb here is take place and can most simply be represented by the predicate TAKE-PLACE. The subject of this verb is process and the verb does not take a second argument.

P8 (TAKE-PLACE PROCESS)

This proposition is negated:

P9 (NEGATE P8)

The argument of P8, PROCESS, is modified by this. What is this process? Looking at the first sub-sentence, it seems that this process refers to biotransformation and therefore means the process is biotransformation which is a "NOUN is NOUN" construction. Process is not a member of the set of things called biotransformation, so ISA is not correct here. The process is biotransformation does seem to say that process is the same thing, the same referent, as

biotransformation and so REF should be used.

P10 (REF PROCESS BIOTRANSFORMATION)

The second clause is "a drug entering the body may act indefinitely". The main verb is a double construction may act whose subject is drug. May is represented using POSSIBLE:

P11 (MOD P12 POSSIBLE)

What is possible is that drugs act:

P12 (ACT DRUG)

This proposition is modified by indefinitely. Indefinitely here expresses some period of time and so MOD is not used. Since indefinitely is not a particular point in time, TIME is inappropriate and DURATION-OF should be used.

P13 (DURATION-OF P12 INDEFINITE)

The argument DRUG of P12 is modified by a phrase, entering the body, which uses the participle entering. Participles can be represented by the predicate of the verb of which they are a part, in this case ENTER. What is doing the entering is a drug, and what is being entered is the body, so:

P14 (ENTER DRUG BODY)

Now we can return to P7 and fill in the correct arguments to the IF connective. Interpreting the connective as between the arguments, the representation will be of drugs may act IF the process does not take place.

P7 (IF P11 P9)

S2:P1 (INVOLVE BIOTRANSFORMATION REACTION)
P2 (OF BIOTRANSFORMATION AGENT)
P3 (MOD AGENT HARMFUL)
P4 (MOD REACTION OXIDATION)
P5 (MEDIATE ENZYME REACTION)
P6 (MOD ENZYME COMPLEX)
P7 (IF P11 P9)
P8 (TAKE-PLACE PROCESS)
P9 (NEGATE P8)
P10 (REF PROCESS BIOTRANSFORMATION)
P11 (MOD P12 POSSIBLE)
P12 (ACT DRUG)

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P13 (DURATION-OF P12 INDEFINITE)
P14 (ENTER DRUG BODY)
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The third sentence is:

S3:Biotransformation defends the body against the effects of toxins and is carried out in the liver.

Here there are two clauses linked by and, but once again this is not a logical connective and the and is not represented. The clauses should be considered separately, and the first is:

S3A: Biotransformation defends the body against the effects of toxins.

The verb is defends and its subject is biotransformation, its object body. Defend normally takes the preposition against but this will not be included as part of the verb here, in order to avoid a three argument verb.

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S3:P1 (DEFEND BIOTRANSFORMATION BODY)
   P2 (AGAINST P1 EFFECT)
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The effect of toxins is a straightforward POSSESS:

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P3 (POSSESS TOXIN EFFECT)
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The second clause is:

S3B: (biotransformation) is carried out in the liver.

Here the verb is carry-out in passive form, where the surface subject biotransformation is the logical object, and there is no logical subject supplied to fill the first argument of the verb.

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P4 (CARRY-OUT $ BIOTRANSFORMATION)
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This proposition is modified by a prepositional phrase of location:

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P5 (IN P4 LIVER)
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S3:P1 (DEFEND BIOTRANSFORMATION BODY)
   P2 (AGAINST P1 EFFECT)
   P3 (POSSESS TOXIN EFFECT)
   P4 (CARRY-OUT $ BIOTRANSFORMATION)
   P5 (IN P4 LIVER)
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The fourth sentence:

S4: The liver, weighing three pounds in the human adult, is the largest organ in the body and performs diverse functions.

Here, once again, there is a non-logical and connecting two separate clauses. The first clause is:

S4A: The liver, weighing three pounds in the human adult, is the largest organ in the body.

The main verb is is. The relationship between liver and organ is clearly an ISA relationship: liver is a member of the class organ.

S4:P1 (ISA LIVER ORGAN)

Both arguments to this proposition are modified, the first, liver, by weighing three pounds in the human adult. Weighing is a participle represented by the predicate WEIGH. WEIGH can be used in two quite different ways: for example, "I weighed the cat. The cat weighs six pounds". The first sentence here shows weigh with a simple structure: (WEIGH I CAT) In the second, the cat is not doing the weighing although cat is the surface subject. This is the same use of weigh as in the liver weighs three pounds. One way to represent this is to use AMOUNT-OF:

P2 (WEIGH $ LIVER)
P3 (AMOUNT-OF P2 POUND)
P4 (NUMBER-OF POUND THREE)

Another way to represent this is to consider WEIGH as a two argument verb that has two possible structures: WEIGH SUBJECT OBJECT or WEIGH SUBJECT AMOUNT. Inspection of the proposition would be needed to determine which structure was being used. Thus:

P2 (WEIGH LIVER POUND)
P3 (NUMBER-OF POUND THREE)

For scoring recall protocols, this second method is simpler and, in some ways, it seems more natural to consider the liver weighing some pounds as being a single proposition.

In the human adult is straightforward enough:

P4 (IN P2 ADULT)
P5 (MOD ADULT HUMAN)

Note that P4 here assumes that the second method of propositionalizing weighing three pounds was used. If it had been the first, then the two propositions would be labelled P5 and P6, and P5 would be (IN LIVER ADULT).

The modification of organ is the superlative largest represented by a MOD proposition:

P6 (MOD ORGAN LARGEST)

This is modified by a prepositional phrase of location: in the body.

P7 (IN P6 BODY)

The second clause in this sentence is very simple:

S4B: (the liver) performs diverse functions.

P8 (PERFORM LIVER FUNCTION)
P9 (MOD FUNCTION DIVERSE)

S4:P1 (ISA LIVER ORGAN)
P2 (WEIGH LIVER POUND)
P3 (NUMBER-OF POUND THREE)
P4 (IN P2 ADULT)
P5 (MOD ADULT HUMAN)
P6 (MOD ORGAN LARGEST)
P7 (IN P6 BODY)
P8 (PERFORM LIVER FUNCTION)
P9 (MOD FUNCTION DIVERSE)

The fifth sentence is:

S5: Through the large portal vein of the liver passes all the blood that has absorbed digested food and other substances from the intestines.

Here there is a main clause and a compound subordinate clause. In the main clause, "Through the large portal vein of the liver passes all the blood", the main verb, at first glance, is pass whose subject is blood. However, what the blood is doing is passing through a vein and so the predicate is PASS-THROUGH:

S5:P1 (PASS-THROUGH BLOOD VEIN)
P2 (AMOUNT-OF BLOOD ALL)

Vein is modified by both large and portal and by of the liver.

P3 (MOD VEIN PORTAL)

P4 (MOD VEIN LARGE)
P5 (POSSESS LIVER VEIN)

The subordinate clause, "that has absorbed digested food and other substances from the intestines", once again has a non-logical and. That represents blood and is the logical subject of the verb absorb.

P6 (ABSORB BLOOD FOOD)

From the intestines modifies this proposition and so:

P7 (FROM P6 INTESTINE)

Food is modified by digested:

P8 (MOD FOOD DIGESTED)

The second predicate proposition is:

P9 (ABSORB BLOOD SUBSTANCE)

The prepositional phrase also applies to this proposition:

P10 (FROM P9 INTESTINE)

Substance is modified by other and this can be represented by a MOD proposition:

P11 (MOD SUBSTANCE OTHER)

When the meaning of other in this context is examined, it seems that other is being used as a disguised comparative and that what is really being said here is substances other than food;

P11 (OTHER-THAN SUBSTANCE FOOD)

Either way the meaning is clear.

S5:P1 (PASS-THROUGH BLOOD VEIN)
P2 (AMOUNT-OF BLOOD ALL)
P3 (MOD VEIN PORTAL)
P4 (MOD VEIN LARGE)
P5 (POSSESS LIVER VEIN)
P6 (ABSORB BLOOD FOOD)
P7 (FROM P6 INTESTINE)
P8 (MOD FOOD DIGESTED)
P9 (ABSORB BLOOD SUBSTANCE)
P10 (FROM P9 INTESTINE)
P11 (MOD SUBSTANCE OTHER)

6.0 USE OF PROPOSITIONAL ANALYSIS IN EXPERIMENTS.

6.1 Scoring Recall Protocols.

The scoring methods usually used in the propositional framework involve all-or-none scoring; a proposition is counted either as recalled, or as not recalled. No partial credit is given.

Consistency in scoring is the most important aspect of scoring from the experimenter's point of veiw. Hence, scoring of subject recall protocols demands that criteria be established so that scoring is consistent. Criteria can be strict, allowing only close reproductions of propositions, or they can be liberal, "gist" scoring. Our experience is that strict scoring is much easier to perform and results in more consistency than liberal scoring. Most of the time, we have seen little difference in the patterns of effects appearing under the two criteria, so strict scoring appears to be the best approach. However, it is important to keep in mind that strict scoring is very sensitive to similarities in the surface form between the recall protocol and the to-be-recalled text. Scorings of intermediate degrees of strictness and liberality can also be done, although there seems to be no advantage in doing so.

Strict scoring can be defined as giving credit for a proposition only when it is closely reproduced in the protocol. Because subjects rarely produce protocols that are word for word exactly like the original text, some degree of latitude in interpretation is necessary. However, such latitude must be defined and limited or the scoring will no longer be strict. Thus, what we mean by "close reproduction" is that the proposition must be reproduced in the protocol exactly or by a close synonym, but care must be taken to ensure that the synonyms accepted really are close. One way to define a close synonym would be to use dictionary definitions. Thus, hepatic portal vein would be a strict reproduction of portal vein of the liver since, by definition, hepatic means of the liver.

Guidelines must also be established for dealing with embedded propositions. In strict scoring credit is given only for propositions that have other propositions as arguments if the proposition in the argument position is also present in the protocol.

Liberal scoring can be of several degrees of liberality. We have found a very liberal set of criteria to be the most useful form of liberal scoring. Our criterion is to give credit for those propositions either explicitly present, or directly implied by the protocol. By directly implied, we mean "what propositions must the subject have had in memory in order to say what was said in the protocol?". This obviously will result in an extremely

subjective scoring, although this is a problem with all liberal scorings. If the scorings are done blind to any experimental manipulations, and efforts are made by scorers to be consistent across subjects and passages, then this subjective quality should not be a problem. However, clearly there will be more "noise" in a liberal scoring than in a strict, and so effects will not be as clean and clear-cut. If the level of recall is so low that there is a floor effect with strict scoring, the liberal scoring may be useful.

6.2 Example Protocols and Scoring.

The actual recall protocols shown in Table 2 are from the passage propositionalized earlier (see Sec. 5.2, Table 1).

A scoring of these protocols for both strict and liberal criteria is shown in Table 3. Some points of scoring policy can be illustrated using these examples.

For subject 1 on the strict scoring, credit was given for only two propositions, S1:P11 and S2:P10. The protocol is not very close to the original, unlike subject 2 for instance, so this low score is not suprising. The proposition S2:P10 is obviously credited for biotransformation is the process. S1:P11 was credited because carcinogenic was judged to mean cancer causing and substance was acceptable as a synonym for chemical. A case could be made that carcinogenic means able to cause cancer and that P10 should therefore have been given credit for as well. However, the strict decision not to do so was applied consistently to all subjects, and so this problem is not important.

Notice that S5:P7 and P11 were not given credit for subject 1 in the strict scoring. This is because the embedded proposition could not be given credit for on the strict scoring.

A point that is not fully illustrated in these examples is the treatment of arguments of REF and ISA propositions. REF means SAME-AS and the two arguments are therefore equivalent. Thus, any propositions using one argument are synonymous with similar propositions using the other. It was decided to give credit for these on the strict scoring only if the REF proposition was explicit in the protocol. Thus, subject 3 did not get credit for biotransformation did not occur because the text has the process did not take place, and the (REF PROCESS BIOTRANSFORMATION) proposition is not in the protocol. Of course, in the liberal scoring credit could be given for this.

Table 2.

Example recall protocols.

Subject 1:
Biotransformation is the process by which your body rids itself from various unneeded foods, toxins and carcinogenic substances. The food, toxin, or whatever, goes through your liver from your large intestine where it is further cleaned and then expelled or utilized. The liver is your largest ...

Subject 2:
The liver (at about three pounds in the adult human) is the largest organ in the human body. The portal vein carries all the blood that contains digested food from the intestines to the liver. Biotransformation is the enzymatic process by which toxins and environmental pollutants are detoxified in the body. Without this process, many toxins would remain in their toxic state.

Subject 3:
The liver processes all the blood in the body. It serves many purposes, one of which is to break down the chemical form of toxic materials. This is done through an oxidation reaction known as biotransformation. If biotransformation did not occur many noxious substances would remain in the bloodstream indefinitely.

Table 3.

Proposition	Subject	Criterion: Strict 1	Strict 2	Strict 3	Liberal 1	Liberal 2	Liberal 3
S1: P1	(REF BIOTRANSFORMATION TRANSFORMATION)						
P2	(MOD TRANSFORMATION CHEMICAL)						
P3	(CAUSE TRANSFORMATION INACTIVATION)						
P4	(OF INACTIVATION DRUG)						
P5	(CAUSE TRANSFORMATION DETOXIFICATION)		X			X	
P6	(OF DETOXIFICATION POLLUTANT)		X			X	
P7	(MOD POLLUTANT ENVIRONMENTAL)		X			X	
P8	(CAUSE TRANSFORMATION DEACTIVATION)				X		
P9	(OF DEACTIVATION CHEMICAL)				X		
P10	(ABLE-TO CHEMICAL P11)						
P11	(CAUSE CHEMICAL CANCER)	X			X		
S2: P1	(INVOLVE BIOTRANSFORMATION REACTION)					X	
P2	(OF BIOTRANSFORMATION AGENT)						
P3	(MOD AGENT HARMFUL)						
P4	(MOD REACTION OXIDATION)			X			X
P5	(MEDIATE ENZYME REACTION)					X	
P6	(MOD ENZYME COMPLEX)						
P7	(IF P11 P9)					X	X
P8	(TAKE-PLACE PROCESS)		X			X	X
P9	(NEGATE P8)		X			X	X
P10	(REF PROCESS BIOTRANSFORMATION)	X	X		X	X	X
P11	(MOD P12 POSSIBLE)					X	
P12	(ACT DRUG)						X
P13	(DURATION-OF P12 INDEFINITE)					X	X
P14	(ENTER DRUG BODY)						X
S3: P1	(DEFEND BIOTRANSFORMATION BODY)						
P2	(AGAINST P1 EFFECT)						
P3	(POSSESS TOXIN EFFECT)						
P4	(CARRY-OUT $ BIOTRANSFORMATION)						
P5	(IN P4 LIVER)						
S4: P1	(ISA LIVER ORGAN)		X			X	
P2	(WEIGH LIVER POUND)		X			X	
P3	(NUMBER-OF POUND THREE)		X			X	
P4	(IN P2 ADULT)		X			X	
P5	(MOD ADULT HUMAN)		X			X	
P6	(MOD ORGAN LARGEST)		X		X	X	
P7	(IN P6 BODY)		X			X	
P8	(PERFORM LIVER FUNCTION)			X			X
P9	(MOD FUNCTION DIVERSE)			X			X
S5: P1	(PASS-THROUGH BLOOD VEIN)		X		X	X	X
P2	(AMOUNT-OF BLOOD ALL)		X	X		X	X
P3	(MOD VEIN PORTAL)		X			X	
P4	(MOD VEIN LARGE)						
P5	(POSSESS LIVER VEIN)					X	X
P6	(ABSORB BLOOD FOOD)		X		X	X	
P7	(FROM P6 INTESTINE)		X		X	X	
P8	(MOD FOOD DIGESTED)		X			X	
P9	(ABSORB BLOOD SUBSTANCE)				X		
P10	(FROM P9 INTESTINE)				X		
P11	(MOD SUBSTANCE OTHER)				X		
	Total:	2	19	4	11	25	13

ISA is treated differently from REF. Here the first argument is a member of the class defined by the second. If the ISA relationship is explicit in the protocol, it seems reasonable to decide that propositions about the second argument are also about the first: that is, propositions about a class apply to individual members of that class. The reverse is not, however, true: propositions that apply to a member of a class may not apply to the class itself.

This passage, as already shown, provides a good illustration of the treatment of REF but not, as it happens, of ISA. But an example can be given from another text and is shown in Table 4. Subject 1 would get credit for all three propositions, while subject 2 would only get credit for P2 and P3.

6.3 Propositional Analysis for "Main Idea" Experiments.

In our "main idea" experiments, subjects were asked to summarize a paragraph-length passage as a single, brief (80 characters), complete sentence stating the main idea of the passage. We then studied how the content of these responses varied with manipulations of the presented passages, which typically involved two versions of the same body of material. The method basically consists of propositionalizing the responses, making them as similar as similar as possible, and then separating the responses according to the original version and comparing the two resulting sets of response propositions. Since the process is done blind to which version the subject saw, the method results in a rigorous comparison of the response content.

6.3.1 Subject Response Propositionalization. - Because the goal of this propositionalizing of responses is different from propositionalizing texts for use in recall experiments, the method is also somewhat different. We analyze responses in two steps. The first step consists of propositionalizing the responses, and the second of reducing the number of unique or idiosyncratic response representations by finding synonymous propositions and arguments, grouping them together and replacing each member of the group with a group label. Because propositionalizing subject responses is the first of the two steps, the propositionalization can be much more surface oriented and so much easier to perform than recall text propositionalization. Several examples of this surface oriented response propositionalization have already been given in this report. Experience shows that it is much faster and more effective to propositionalize in this way, leaving differences in expression to be ironed out by the "synonymization" process. Sometimes, too, it is almost impossible to decide what a subject meant, and a

Table 4.

ISA propositions in recall scoring.

Text:

The corona, a hot gas, produces the solar wind.
P1 (PRODUCE CORONA SOLAR-WIND)
P2 (ISA CORONA GAS)
P3 (MOD GAS HOT)

Protocols:

Subject 1: The hot corona, which is a gas, produces the solar wind.

Subject 2: The corona is a hot gas and the gas produces the solar wind.

non-committal surface propositionalization is the safest method of dealing with this.

For example, consider:

Ex 1: The Battle of Jutland was slight and worthy only of retreat.

The first clause of this response is easy to propositionalize but in the second, worthy of retreat presents a difficult problem to unravel. The simple surface oriented representation is adequate for this type of analysis.

P3 (WORTHY-OF BATTLE RETREAT)
P4 (MOD P3 ONLY)

Another example is:

Ex 2: The superb practice force of any item may fail.

This response, suprisingly enough, was made to the same passage as the first example, a passage about the Battle of Jutland in World War I. One can guess at what the subject might have had in mind; the passage talks about how the Germans had practiced certain maneuvers that enabled them to extricate themselves from the danger posed by a greatly inferior tactical position during the battle. The passage also states that despite some success for the Germans in the battle, their fleet never again left harbor and so the battle must be considered a defeat for them. Knowing this background information certainly helps to understand the sort of lines the subject might have been thinking along. But it does not provide enough information to know what item is supposed to represent, for example. We simply propositionalized this response in a literal, surface fashion.

Ex 2: P1 (MOD P2 POSSIBLE)
P2 (FAIL FORCE)
P3 (MOD FORCE SUPERB)
P4 (MOD FORCE PRACTICE)
P5 (POSSESS ITEM FORCE)
P6 (MOD ITEM ANY)

One very useful procedure to follow during the propositionalization step is to observe and keep in mind obvious synonyms. When there are several ways to propositionalize a particular phrase, one should be chosen that will make the structure of similar phrases easily comparable. Then the second step of finding synonyms will be greatly simplified. For example:

Ex 1: A variety of purposes.
P1 (MOD PURPOSE VARIETY-OF)

Ex 2: Various purposes.
P1 (MOD PURPOSE VARIOUS)

There are several ways to propositionalize Ex 1, but the best would be one similar to that used for Ex 2, as shown. The second step would then consist simply of noting that variety-of and various were synonyms and replacing them with a single term.

Another example is:

Ex 3: Many cultures.
P1 (NUMBER-OF CULTURE MANY)

Ex 4: A lot of civilizations.
P1 (NUMBER-OF CIVILIZATION A-LOT)

Another good example of propositionalizing in order to make similarities and synonyms more obvious is to be found earlier in this report. (See Sec. 3.4.4).

6.3.2 "Synonymizing" Subject Main Idea Responses. - In our method, after subject main idea responses are propositionalized, the proposition lists for the subjects are entered on to a computer. A program written in the LISP programming language processes these lists and produces a list showing predicates, arguments and propositions listed in order of frequency of occurrence for the whole set of data. These predicates, arguments and propositions are then compared and when synonyms are found all members of a synonym group are replaced by a group label. Copies of the LISP program can be obtained by writing to David E. Kieras, Department of Psychology, University of Arizona, Tucson, AZ 85721.

For example, one passage we used was about a performer's ability to control tone and pitch on different keyboard instruments. In the argument list, 4 subjects used the argument PERFORMER, 5 used PLAYER and 1 used PERSON. It was judged that all three of these arguments were synonymous. Because the passage itself used performer every occurrence of PERFORMER, PLAYER and PERSON in the proposition lists was replaced by &PERFORMER. The "&" shows that this is a group label and a record was kept of which original arguments belonged to this group.

A similar process is used for predicates and also for propositions. Particularly for propositions, and to a lesser extent for predicates, reference to the subject's original proposition list may have to be made. This is because it is not always clear exactly what a subject means, or whether two propositions are synonyms, just by examining an isolated proposition.

For example, the predicates ON and POSSESS do not seem to be likely synonyms but when the subject's proposition list contained (ON EXPRESSIVENESS PIANO) it seemed reasonable to consider this a synonym of (POSSESS PIANO EXPRESSIVENESS). Similarly, (AS-REFINED-AS CLAVICHORD PIANO) and (MORE-SOPHISTCATED-THAN PIANO CLAVICHORD) are not obviously synonymous but the original responses from which they were derived seemed to be:

Ex 1: The clavichord is not as refined as the piano.

Ex 2: The piano is more sophisticated than the clavichord.

These responses really seemed to say the same thing in different ways, and so (MORE-SOPHISTICATED-THAN PIANO CLAVICHORD) was used for both subjects.

Now that the principles for our synonymizing process have been described, a procedure will now be outlined.

Step 1: List all predicates, arguments, and propositions with LISP program.

Step 2: Synonymize predicates and arguments.

Step 3: List all predicates, arguments, and propositions in synonymized list with LISP program.

Step 4: Correct oversights in predicates and arguments.

Step 5: Synonymize propositions.

Step 6: Produce final version of list with LISP program.

Synonymizing the propositions is done only after step 4 because working with the propositions can be difficult enough, especially if there is a large number of subjects. This difficulty is reduced by not having to waste time working on a proposition only to discover that a change in predicates would have changed it anyway. This is an important consideration when there can be 400 different original propositions to be examined.

To further simplify the data, steps 1 through 5 can be done twice; the first time using strict criteria for synonymity and the second time using liberal ones. The number of different terms will be considerably reduced after using the liberal criterion which makes the data much simpler to work with.

After the synonymization is complete, the same LISP program is used to produce lists broken out by different experimental conditions. The lists can then be compared and differences between conditions noted.

Reference Notes

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